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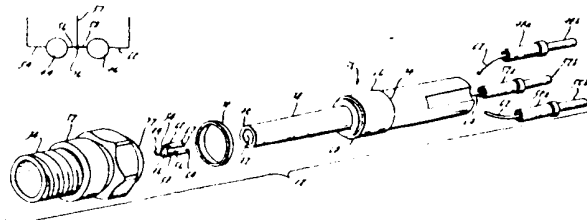
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54 **Gas sensor.**

57 A gas sensor comprises two ceramic sensor members (44, 46) connected electrically in series and arranged for exposure to the hot gaseous combustion by-products produced by an internal combustion engine. One (46) of the ceramic sensor members is a variably resistive partial pressure of oxygen responsive and temperature responsive ceramic, such as, for example, titania. The other (44) of the ceramic sensor members is a variably resistive temperature responsive ceramic thermistor. The sensor members are positioned in the exhaust gas conduit by a ceramic insulator (36) having a plurality of longitudinal passages extending therethrough. A plurality of electrical terminal members (48, 50, 52) are received within the rear of the longitudinal passages. Electrical leads (54, 56, 58, 60) extend from the chips to the terminal members (48, 50, 52) through a plurality of passages and support the chips (44, 46) while providing electrical communication between the chips and the electrical terminals. The electrical terminals (48, 50, 52) are adapted for communication to electronic and/or electrical utilization means. The partial pressure of oxygen responsive exhaust gas sensor member (46) exhibits a rapid change in an electrical property responsive to differences in the exhaust gas chemistry and to differences in exhaust gas temperature. The thermistor sensor member (44) exhibits a similarly rapid change in an elec-

trical property responsive to differences in exhaust gas temperature. For temperatures in the range of from about 700°F (370°C) to about 1500°F (815°C), the application of a reference voltage across the series connected ceramic sensor members (44, 46) will produce a voltage variation across either chip in response to changes in exhaust gas chemistry which is substantially temperature independent.



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SPECIFICATION

TITLE

GAS SENSOR

DESCRIPTION

1 This invention relates to gas sensors.

It has been determined that the operation of a conventional automotive internal combustion engine produces substantial quantities of deleterious gaseous combustion by-products. The principal pollutants so produced are hydrocarbons, carbon monoxide and various oxides of nitrogen. Extensive investigation into the combustion process, examination of the alternative combustion processes and detailed studies of exhaust gas treatment devices have led to the conclusion that the use of a catalytic converter within the exhaust system of an internal combustion engine provides a practical and effective technique for substantially reducing the emission of the deleterious gaseous combustion by-products into the atmosphere. A catalytic exhaust treatment device or converter which is capable of substantially simultaneously converting all three of the aforementioned principal pollutants into water, carbon dioxide, and gaseous nitrogen is referred to as a "three-way" catalyst. However, for the known three-way catalyst devices to be most effective, the gaseous by-products introduced into the converter must be the by-products of combustion of a substantially stoichiometric air/fuel mixture. Such three-way catalysts are said to have a very narrow "window" of air/fuel ratios at which the device is most efficiently operative on the three principal pollutants. By way of example, if λ is the air/fuel ratio normalized to stoichiometry, the window may extend from about 0.99λ to about 1.01λ . Such a three-way catalytic converter is described, for example, in United States Letters Patent 3,895,093. For air/fuel ratios of the combustion mixture on either side of the window, one or two of the principal pollutants will be converted in only very small percentages. Within the window, the three principal pollutants will be converted at very high percent efficiencies approaching 90% in some cases. In view of the narrowness of the catalytic converter window, it has been determined that the associated internal combustion engine should be operated with a combustible mixture having an air/fuel ratio as close as possible to stoichiometry.

The most satisfactory technique for assuring continuous or substantially continuous operation at the desired air/fuel ratio is through the utilization of an appropriate feedback control mechanism. In implementing suitable feedback control systems, it has been proposed to employ sensors responsive to the chemistry of the exhaust gases, that is, the

1 hot gaseous by-products of combustion, in order to control the precise
air content and/or fuel content of the air/fuel mixture being provided
to the engine.

5 One type of electrochemical exhaust gas sensor employs a ceramic
material which demonstrates a predictable electrical resistance change
when the partial pressure of the oxygen of its environment changes. An
example of such a material is titania (titanium dioxide having a general
formula TiO_2). Such sensors can be fabricated generally in accordance
with the teachings of United States Letters Patent 3,886,785. Tests of
10 such devices have shown that at elevated and substantially constant tem-
peratures, the devices will demonstrate a virtual step change in resis-
tance for rich-to-lean and lean-to-rich excursions of the air/fuel ratio
of the combustion mixture producing the exhaust gas environment of the
device.

15 A principal difficulty which has been encountered with such
variable resistive devices resides in the fact that such devices often
demonstrate a measurable resistance change which is also a function of
change of the temperature of the ceramic material, for example, a change
of about $500^{\circ}F$ ($260^{\circ}C$) produces a measurable resistance change on the
20 order of magnitude of a sensed rich-to-lean or lean-to-rich air/fuel
mixture change. Such a temperature variation can be encountered, depen-
ding of course to some extent on the location of placement of the sensor
within an exhaust system, during acceleration of the associated engine
from idle speed to highway speeds. Heretofore, exhaust gas sensors which
25 employed a variable resistance sensor ceramic have required that the
temperature of the material be relatively closely controlled for reliable
use in a feedback system intended to provide an internal combustion en-
gine with very precise air/fuel ratio control.

30 Temperature control of the associated sensor has required the
addition of expensive electronic temperature sensing and heating control
systems external to the exhaust conduit and the addition of a heater ele-
ment situated internally of, or in close proximity to, the sensor element.
In order to narrow the operational range of temperature of the sensor,
the sensor has been operated at the higher end of the predictable range
35 of exhaust gas temperatures thus requiring substantially continuous app-
lication of heat energy for most of the operating cycles of the associated

1 engine. While such devices have continued to be of rugged construction,
the addition of the heater and associated electronics devoted to temper-
ature control have increased cost and have increased risk of failure.
An additional problem which has been encountered is a ceramic fracture
5 problem believed to be associated with thermal shock caused by the rapid
heating of the ceramic material by the heater element. For less precise
operation, such devices have been required to be installed at a location
in an exhaust gas environment where the temperature of the exhaust gases
will not vary substantially for variation in the operating cycle of the
10 associated engine.

According to the present invention, there is provided a gas sen-
sor comprising a first sensor element having an electrical resistance
which varies in response to changes in physical properties of a gas
stream, and electrical connections thereto whereby a voltage may be
15 applied across the sensor element characterised in that the first sensor
element is connected in series with a second sensor element having an
electrical resistance which varies in response to changes in a physical
property of the gas stream and in that an electrical junction is formed
between the first and second elements at which the voltage between the
20 elements may be detected.

The resistances of the sensor elements may vary in response to
any desired physical properties of the gas stream. In the preferred
manner of application of the invention, the resistances vary in response
to temperature and partial oxygen pressure.

25 Preferably therefore, the sensor comprises a pair of electrically
series connected variable resistance ceramic sensor elements. One of
the ceramic sensor elements is a variably resistive partial pressure
of oxygen responsive and temperature responsive ceramic such as, for
example, titania. The other of the ceramic sensor members is a variably
30 resistive temperature responsive thermistor. The ceramic sensor members
are connected electrically in series and are arranged to define a volt-
age divider network. When a reference voltage is applied across the
voltage divider network, the voltage appearing at the junction between
the ceramic sensor members may define the output voltage of the exhaust
35 gas sensor construction. The voltage appearing at the junction of the
sensor elements in the voltage divider network will be relatively tem-
perature independent since temperature effects on the ceramic members
will be electrically complementary. By comparing the output voltage to

1 the voltage level at either end of the voltage divider network a use-
ful output signal may be derived. By selectively referencing to de-
fine the output signal as either the voltage drop across the partial
5 thermistor sensor member, the resulting output signal can be rendered
to be high in the region of λ values less than 1.0 or to be high in the
region of λ values greater than 1.0.

An embodiment of the invention will now be described, by way of
example only, with reference to the drawings, in which:-

10 Figure 1 illustrates an example of an electrical or electronic
exhaust gas sensor responsive control system with which the present in-
vention is of utility.

Figure 2 illustrates an exhaust gas sensor construction according
to the present invention.

15 Figure 3 illustrates, in an exploded view, an exhaust gas sensor
including the present invention and according to Figure 2.

Figure 4 illustrates the electrical series connection of the
exhaust gas responsive ceramic sensor members according to the present
invention.

20 Referring now to the drawing wherein like numbers designate like
structure throughout the exhaust gas conduit 10 of, for example, an inter-
nal combustion engine, not otherwise illustrated, is shown. An exhaust
gas sensor 12 is mounted in conduit 10 so as to place exhaust gas res-
ponsive elements or members of the sensor within the stream of exhaust
25 gases flowing through conduit 10. Exhaust gas sensor 12 may be threaded-
ly received by a suitable land or boss provided therefor on exhaust gas
conduit 10. Alternatively, such a land or boss may be provided on the
conventional exhaust manifold whereby exhaust gas sensor 12 may be placed
in closer proximity to the combustion chambers of the engine. In this
30 regard, the selected location for placement of the exhaust gas sensor 12
within the exhaust system of the engine will be a function of the anti-
cipated normal operating temperature of the selected location, the ease
of servicing the sensor 12 in the selected location, the effects, if any,
of electrical interference on or by ancillary electrical or electronic
35 devices and general convenience. However, the selected location pre-
ferably will be upstream from the contemplated catalytic exhaust gas
treatment device, not shown, and at a location exposed to the exhaust

1 gases from all combustion chambers of the engine. The exhaust gas sensor 12 is arranged to communicate electrically with an electrical control means 14 over sensor electrical leads 16, 18, 20. The electrical control means 14 is arranged to communicate electrically with, for example, an air/fuel ratio modulator means, not shown, by way of modulator means lead 22.

5 An air/fuel ratio modulator means may be, for example, in the case of an electrically or electronically controlled fuel delivery system, a variable resistor arranged to control the quantity of fuel delivered to an engine in respect of a given quantity of air or, in the case of a mechanically or electromechanically controlled fuel delivery system such as a carburetor, a variably positionable metering orifice arranged to control the quantity of fuel delivered to an engine in respect of a given quantity of air. The air/fuel ratio modulator means alternatively may be arranged to control a variably positionable air valve so that the quantity of air ingested by the engine in respect of a given quantity of fuel may be controllably modulated. It will be appreciated that other applications exist for use of sensor 12, such as, for example, a furnace fuel control.

15 Referring specifically to Figure 1, a representative electrical control means 14 is illustrated in a block diagram. Reference voltage source 24 receives electrical energy, for example from the vehicle battery 26 and/or the conventional vehicle electrical charging system, not shown, via electrical bus 28. Reference voltage source 24 communicates with exhaust gas sensor 12 by way of sensor electrical leads 16, 18. Exhaust gas sensor 12 communicates via sensor electrical lead 20 with modulator control signal generator 30. Modulator control signal generator 30 also receives electrical energization from bus 28.

20 Modulator control signal generator 30 is adapted to generate an electrical signal on modulator means lead 22 as a function of the voltage signal appearing on sensor electrical lead 20. Modulator control signal generator 30 is preferably adapted to generate an output signal of a magnitude and electrical polarity which is suitably tailored to coact with an air/fuel ratio modulator means to increase or decrease the air/fuel ratio of the combustion mixture being provided to the associated engine in order to provide an exhaust gas composition flowing within conduit 10 which will be sensed by exhaust gas sensor 12 as being the gaseous by-

1 products of combustion of a combustible mixture having a selected, for
example, stoichiometric, air/fuel ratio. Modulator control signal gener-
ator 30 may operate to compare the signal received on sensor lead 20 from
5 exhaust gas sensor 12 with a reference signal indicative of the exhaust
gas sensor signal generated by an exhaust gas composition produced by
combustion of an air/fuel mixture having the desired air/fuel ratio.
Deviation of the signal on lead 20 from a value indicative of the desired
ratio will cause a suitable, corrective, signal to be generated on modu-
lator means lead 22 to initiate suitable correction of, for example, the
10 fuel content of the combustible mixture. Modulator control signal gener-
ator 30 should be designed and tailored to take into account the time
lag associated with the transport properties of the associated engine and
the time period required for a change in air/fuel ratio to be recognised
by exhaust gas sensor 12.

15 Referring now to Figures 2 and 3 and particularly to Figure 3,
exhaust gas sensor 12 incorporating the present invention is illustrated
and one possible method of assembly is described. Exhaust gas sensor 12
is provided with a housing means 32 which is threaded as at 34 for engage-
ment with a suitably threaded aperture provided therefor within exhaust
20 gas conduit 10. A ceramic insulator member 36 extends through housing
means 32 and includes a forwardly projecting sensor support portion 38.
Sensor support portion 38 includes forwardly projecting collar 40 which
defines a well or cavity 42. The sensor 12 includes a pair of ceramic
sensor elements or members 44, 46 received within well 42. Three elec-
25 trical terminal members 48, 50, 52 extend rearwardly from ceramic insul-
ator member 36. Electrical terminal members 48, 50, 52 are adapted for
receipt of suitable mating connectors, not shown, to electrically commun-
icate exhaust gas sensor 12 with the electrical control means 14.

30 The insert portions 48a, 50a, 52a of each of the electrical ter-
minal members 48, 50, and 52 may be cemented into position within the
rear portion of ceramic insulator member 36. The preferred cement is
a catalytic agent, low temperature curable cement which cures to a high
density. Such a cement is Sauereisen #31. The terminal members 48,
50 and 52 are arranged to project a contact portion 48b, 50b and 52b of
35 each terminal member 48, 50 and 52 rearwardly from the rear face of
ceramic insulator member 36.

1 The ceramic sensor elements 44, 46 comprise a partial pressure
of oxygen responsive ceramic such as titania, for example sensor element
45, and a temperature compensating thermistor, for example sensor element
44. As used herein, "thermistor" refers to an electronic device which
5 has an electrical parameter or property such as its electrical resistance
which varies rapidly and predictably with the temperature of the device
and which parameter or property varies only slightly, if at all, in short
periods of time in response to changes in the partial pressure of oxygen
of the environment of the device. In order to accomplish the objectives
10 of the instant invention, the thermistor element, ceramic sensor element
44, is connected electrically in series with the partial pressure of oxy-
gen responsive element 46 to change its electrical parameter or property
in response to temperature variation. Furthermore, the series-connected
sensor elements 44, 46 are arranged to be exposed to substantially the
15 same exhaust gas environment and are arranged to define a voltage divider
network wherein the usable output signal is derived from the circuit junc-
tion of the thermistor element with the partial pressure of oxygen res-
ponsive sensor element.

Each ceramic sensor element 44, 46 is provided with a pair of
20 electrical leads 54, 56, 58 and 60. Leads 54 and 60 are provided with
individual insulating sleeve members 62. The electrical leads 56, 58
are shown being provided with a further insulating sleeve 64. Insul-
ating sleeves 62, 64 with their interiorly received electrical leads
54, 56, 58 and 60 are threaded through longitudinally extending bores or
25 passages within, and which extend completely through ceramic insulator
member 36 from the bottom of well or cavity 42 to the rear face of cera-
mic insulator member 36. Electrical lead 54 and its associated in-
sulating sleeve 62 are thus inserted into the insert portion 48a of
electrical terminal member 43. The electrical lead 54 is electrically
30 united with the contact portion 43b of terminal member 43. Similarly,
electrical lead 60 and its associated insulator member 62 are inserted
into the insert portion 50a of second electrical terminal 50. The
electrical lead 60 is electrically united with the contact portion 50b
of terminal member 50. The conductor formed by sensor leads 56, 58 and
35 the associated insulator member 64 are similarly inserted into the insert
portion 52a of electrical terminal 52 and the conductive portion thereof
is electrically united with the contact portion 52b of terminal member 52.

1 The ceramic sensor elements 44, 46 are situated within the well
or cavity 42. Projecting collar 40 may thus be operative upon insertion
of the exhaust gas sensor assembly 12 into an exhaust system to shield
the ceramic sensor elements 44, 46 from impact by any solid particles
5 which may be dislodged from the interior surface of the exhaust gas
conduit 10. Collar 40 also protects the electrical leads 54, 56, 58 60
from flexure induced by pressure and exhaust gas flow fluctuations in
the exhaust gas system. Collar 40 further protects the ceramic sensor
elements 44, 46 and their electrical leads 54, 56, 58 and 60 from possible
10 damage during assembly and from handling damage prior to or during installation in a vehicle exhaust system.

Ceramic insulator member 36 is provided with a centrally positioned
enlarged annular portion 66 which is provided with a seal receiving
recess 68 at its forward shoulder. Enlarged annular central portion 66
15 is provided with an abutment shoulder 74 at its rear. The forwardly
projecting portion 38 of ceramic insulator member 36 is inserted through
seal member 70 and seal member 70 is loosely received within recess 68.
The ceramic insulator member 36 is then inserted into housing means 32.
The rear portion 72 of housing means 32 is then crimped or otherwise
20 deformed into close intimate contact with rear shoulder 74 of the central
portion 66 of ceramic insulator means 36 to compressively and sealingly
confine seal member 70 between recess 68 and a suitably provided shoulder
within the central portion of housing means 32. Seal member 70 is operative
to define a fluid tight barrier to flow around insulator member 36
25 through housing means 32. With specific reference to Figure 1, seal
member 70 is operative to establish a fluid tight barrier between the
interior of the exhaust gas conduit 10 and the exterior of exhaust gas
conduit 10.

Referring now to Figure 4, the electrical series connection
30 between ceramic sensor elements 44 and 46 and electrical leads 54, 56,
58 and 60 is illustrated. Electrical leads 56, 58 are electrically
united, as by welding, brazing or soldering, at junction 76. A single
electrical lead 57 extends from junction 76. With reference to Figures
2 and 3, electrical lead 54 communicates, for example, with terminal
35 member 43, electrical lead 60 communicates, for example with terminal
50 and electrical lead 57 may extend through insulating member 64 to
communicate sensor leads 56, 58, for example, with electrical terminal
52. With reference to Figures 1 and 2, electrical terminals, 48, 50

1 of the exhaust gas sensor 12 may be electrically communicated to refer-
ence voltage source 24 by way of conductors 16, 18. Electrical terminal
52 may communicate the junction 76 of leads 56, 58 ceramic sensor ele-
ments 44, 46 to the modulator control signal generator 30 by way of
5 electrical conductor 20.

Reference voltage source 24 may be arranged to generate a pre-
determined constant voltage differential between conductors 16, 18 of,
for example, five (5.0) volts. This voltage differential will be applied
by sensor leads 54, 60 to the voltage divider comprised of ceramic sensor
10 elements 44, 46. As will be discussed hereinbelow, the ceramic sensor
elements 44, 46 will behave as variable resistances in the presence of
hot gases having varying oxygen partial pressure so that junction 76 will
exhibit a voltage which will be indicative of the instantaneous oxygen
partial pressure. By communicating the voltage at junction 76 to modu-
15 lator control signal generator 30, a command signal may be generated for
application by conductor 22 to an air/fuel ratio modulator means to
maintain the combustible mixture provided to the associated engine at a
preselected, for example stoichiometric, air/fuel ratio. By selectively
determining which of leads 16, 18 is to be electrically more positive
20 than the other of leads 16, 18, the voltage appearing at junction 76
will represent the voltage drop across either ceramic sensor element 44
or ceramic sensor element 46. Thus, the voltage appearing at junction
76 can be tailored to demonstrate either a low-to-high or a high-to-low
variation for a selected change in the air/fuel ratio of the combustible
25 mixture being provided to the associated engine.

One of the ceramic sensor elements, for example sensor element
44, is a high temperature thermistor. The other of the sensor elements,
for example sensor element 46, is a variably resistive partial pressure
of oxygen responsive ceramic, such as for example titania, which also
30 demonstrates an electrical resistance variation in response to changes
in its temperature. The thermistor sensor element 44 may be fabricated
according to our copending patent application Serial No. _____
(reference US-918). The partial pressure of oxygen responsive sensor
element 46 may be formed of titania material in the manner described in
35 issued United States Letters Patent 3,836,785. The preferred form of
partial pressure of oxygen responsive ceramic sensor element 46 to be
used in fabricating exhaust gas sensor 12 is the improved form des-
cribed in our copending Patent application Serial No. _____

1 (reference US-919). Preferably, the thermistor member 44 and the partial
pressure of oxygen responsive member 46 are fabricated from the same
metal oxide ceramic forming base material. The advantage of this feature
is discussed hereinbelow.

5 A suitable thermistor ceramic sensor element 44 may be formed,
for example, from substantially pure titania powder. The thermistor
chip member may be fabricated in much the same manner as is taught in
the U.S. Patent 3,836,785 except that the titania powder is processed
to achieve a ceramic material density approaching, as closely as possible,
10 (preferably at least 97% of) the theoretical density of the material.
Densification of the titania ceramic may be accomplished by several
methods including high temperature sintering (sintering at temperatures
in excess of about 2700°F) (1480°C) and/or use of a titania powder
having a particle size range adjusted for maximum densification during
15 sintering. Since we prefer to obtain substantially identical electrical
response to temperature variation from the thermistor, element 44 and
from the partial pressure of oxygen sensor, element 46, substantially
the same titania powder material is used to form both ceramic sensor
elements 44 and 46. Since uniformity of particle size consonant with
20 obtaining a desired ceramic porosity is necessary to produce a satis-
factory partial pressure of oxygen responsive sensor, element 46, high
temperature sintering is relied upon to achieve the desired densifica-
tion of the thermistor sensor, element 44. While tests have indicated
that even densified titania will continue to demonstrate some resis-
25 tance variation as a function of partial pressure of oxygen, it also has
been determined that the time rate of response of resistance changes to
changes in partial pressure of oxygen increases dramatically with in-
creasing density of the titania material. Increases in response time
on the order of 10,000 times have been observed. The time rate of res-
30 ponse for densified titania increases sufficiently that, for all prac-
tical purposes in an internal combustion engine exhaust gas environment,
the dependency of the thermistor resistance on partial pressure of oxygen
and particularly changes in resistance induced by changes of partial
pressure of oxygen can be ignored.

35 The preferred method of fabricating the partial pressure of oxygen
responsive ceramic chip member involves the preparation of a substan-
tially pure titania powder. As titania has two phases, the anatase

1 phase and the rutile phase, and the rutile phase is the high temperature
stable phase, the titania powder should be comprised of a substantial maj-
ority of rutile phase material. In order to convert anatase phase
material to rutile phase material, the material may be calcined, for
5 example for two hours at 2100°F (1150°C), and then ball milled to pro-
duce powder having small particle sizes with the substantial majority
of the powder being rutile phase material. Calcining also improves the
purity of the powder by volatilizing any volatilizable impurities. The
powder should have 100% of the particles smaller in size than 20 microns
10 and should have a substantial majority of the powder with a particle
size smaller than about 10 microns. The processed powders may thereafter
be ball milled with an organic binder solution to form a slurry.

The slurry may be formed onto a tape or sheet of material after
which the slurry may be air dried and cast to form a sheet or tape of
15 material. Suitably sized and shaped sensor element wafers of the air
dried material may then be cut from the tape for further processing. A
pair of lead wires may be inserted into the sensor elements and the sen-
sor elements may thereafter be sintered to a pyrometric cone equivalent
number 9. After the sensor elements have been matured, the matured
20 ceramic elements may be impregnated with a combustion catalyst material
such as platinum or an alloy thereof.

Impregnation may be accomplished by immersing the sensor elements
in a 1:1 solution of 2% chloroplatinic acid and formaldehyde and by
evacuating the container to remove entrapped air. The solution is allowed
25 to flow through the porous sensor element so that substantially all sur-
faces of the grains of the sensor ceramic are exposed to the solution.
The impregnated elements are then air dried and heated in air to a tem-
perature of approximately 1300°F (700°C) for a period of approximately
four (4) hours to assure the reduction of deposited chloroplatinate salts
30 to finely divided particles to the associated titania grains within the
sensor ceramic.

The voltage generated at the electrical junction 76 between the
two temperature-variable resistors in response to a constant voltage
being applied across the series connected elements 44, 46 develops a
35 relatively temperature independent output voltage signal. The output

1 voltage may be given by the expression

$$V_o = V_i \frac{R_{REF}}{R_{TOTAL}} \quad (1)$$

5 where V_o is the output voltage, V_i is the applied or input voltage, R_{REF} is the resistance of the circuit element across which the output voltage is being measured, for example element 44 or element 46, and R_{TOTAL} is the series resistance of both elements 44, 46. If the ratio of the resistances of elements 44 and 46 can be constrained to approach a constant value, the output signal V_o will be relatively unaffected by temperature changes.

10 The resistance of the ceramic elements 44, 46 as a function of temperature can be given by the expression

$$R_{44} = R_1 e^{\frac{\beta_1}{t-t_o}} \quad (2)$$

for the resistance of element 44 and by the expression

$$R_{46} = R_2 e^{\frac{\beta_2}{t-t_o}} \quad (3)$$

15 for the resistance of element 46. R_1 and R_2 correspond to measured resistances at an elevated temperature, t_o , for the elements 44 and 46 respectively while β_1 and β_2 are constants determined by the ceramic material of the elements 44 and 46 respectively. Thus, at any other elevated temperature, t where t is greater than t_o , the resistance of the element 44 or 46 can be readily determined. For values of R_1 and R_2 measured at the same temperature t_o and exposed to the same elevated temperature t_1 the ratio of resistances can be given by the expression

$$\frac{R_{44}}{R_{46}} = \frac{R_1}{R_2} e^{\frac{\beta_1 - \beta_2}{t_1 - t_o}} \quad (4)$$

It can be seen that as β_1 approaches β_2 , the ratio $\frac{R_{44}}{R_{46}}$ approaches the

25 ratio $\frac{R_1}{R_2}$ which is a constant. Thus, the output voltage V_o becomes

relatively independent of temperature when the β material characteristics are selected to be as nearly identical as possible.

By providing a partial pressure oxygen responsive ceramic exhaust gas sensor material which demonstrates a secondary resistance variation in

1 response to temperature variation of its environment with an electrically
series connected thermistor which is exposed to substantially the same
exhaust gas environment, the secondary effects of temperature induced
resistance variation may be substantially reduced or eliminated. By
5 impressing a constant reference voltage across the series connected
exhaust gas responsive ceramic variable resistors, the junction between
the partial pressure of oxygen responsive device and the thermistor will
exhibit a voltage which is relatively temperature independent. That is,
temperature induced resistance variation of the resistance of the partial
10 pressure of oxygen responsive device will be substantially duplicated by
temperature induced resistance variation of the resistance of the therm-
istor device so that the voltage drop across the respective elements
will be substantially unaffected by temperature variations.

By connecting a high temperature thermistor electrically in
15 series with the partial pressure of oxygen responsive ceramic element
and using the electrical junction so established as a voltage divider
for a constant applied voltage, the effects of temperature change on
the output signal from the sensor can be substantially reduced or
eliminated.

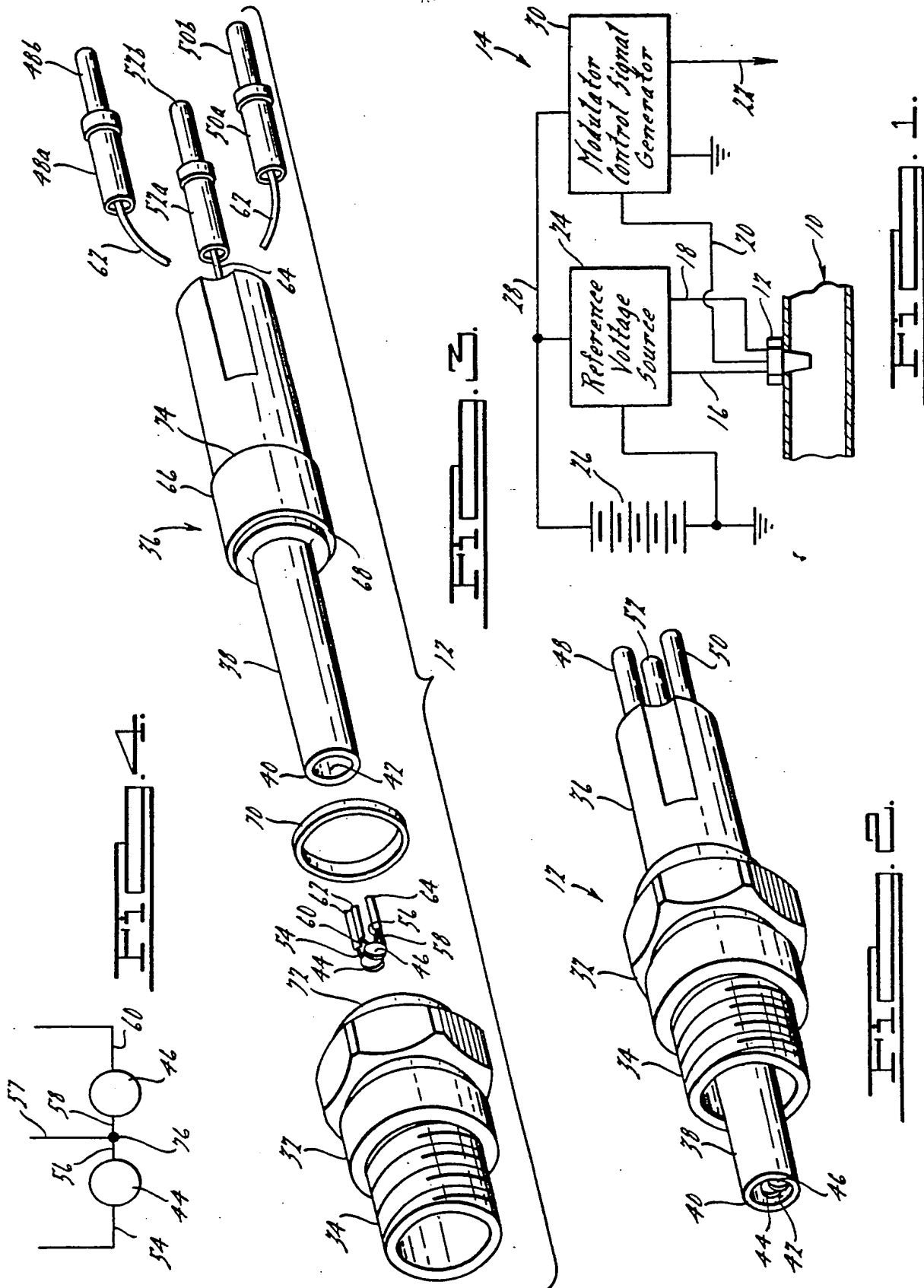
CLAIMS

- 1 1. A gas sensor comprising a first sensor element having an electrical resistance which varies in response to changes in physical properties of a gas stream, and electrical connections thereto whereby a voltage may be applied across the sensor element characterised in
- 5 that the first sensor element is connected in series with a second sensor element having an electrical resistance which varies in response to changes in a physical property of the gas stream, and in that an electrical junction is formed between the first and second elements at which the voltage between the elements may be detected.
- 10 2. A gas sensor according to Claim 1 wherein said first element has an electrical resistance which varies with the partial pressure of oxygen of the gas stream and with the temperature of the gas stream.
- 15 3. A gas sensor according to Claim 1 or Claim 2 wherein said second element has an electrical resistance which varies rapidly as a function of change in the temperature of the gas stream but which varies substantially more slowly as a function of change in the partial pressure of oxygen of the gas stream.
- 20 4. A gas sensor according to any one of Claims 1 to 3 wherein said first element is a metal oxide ceramic variably resistive partial pressure of oxygen responsive element and said second element is a thermistor.
- 25 5. A gas sensor according to Claim 3 or Claim 4 wherein the said second element comprises a body of ceramic material having a density approaching the theoretical density of the ceramic material.
- 30 6. A gas sensor according to any one of Claims 1 to 5 wherein the said first element comprises a porous body composed of grains of ceramic material and particles of a combustion catalyst dispersed throughout the porous body on the surfaces of the grains of the ceramic material.
- 35 7. An exhaust gas sensing device for an engine exhaust system comprising a housing adapted to be mounted in the engine exhaust system and a gas sensor according to any one of Claims 1 to 6 supported in the housing for location in the exhaust gases passing through the exhaust system.
8. A device according to Claim 7 wherein a ceramic insulator having a forwardly-projecting sensor portion, and a rearwardly-extending terminal portion is mounted in the housing, the sensor portion defines

- 1 an open cavity within which the sensor is received, said cavity having
a depth sufficient to shield the sensor from the flow of gaseous com-
bustion products in the exhaust system, and passages in the ceramic
insulator extend rearwardly from the cavity to the terminal portion,
5 and electrical leads from the sensor are received in respective ones
of the passages.

9. Sensing apparatus for detecting changes in a physical pro-
perty of a gas stream comprising a gas sensor or sensing device
according to any one of Claims 1 to 8 and means for detecting voltages
10 across the first element and across the second element electrically
connected to the elements and to the junction.

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European Patent
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EUROPEAN SEARCH REPORT

0001512

Application number

EP 78 30 0466

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl.)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
X	<u>US - A - 4 001 756 (PHILIPS)</u> * Column 2, line 14 - column 4, line 45, claims 1,2 *	1,2	H 01 C 7/04 G 01 N 27/16
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	<u>FR - A - 2 280 057 (FIAT)</u> * Page 4, lines 4-24, claims 1,3,7,8 *	2-4	
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	<u>FR - A - 2 172 441 (REGIE NATIONALE DES USINES RENAULT et AUTOMOBILES PEUGEOT)</u> * Page 1, line 24 - page 2, line 11; claims 1,3,5,7 *	6	TECHNICAL FIELDS SEARCHED (Int. Cl.) H 01 C 7/04 7/00 G 01 N 27/12 27/16 C 04 B 41/04 35/06
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	<u>US - A - 4 011 655 (FORD)</u> * Column 3, line 53 - column 8, line 22; figures *	7,8	

			CATEGORY OF CITED DOCUMENTS X: particularly relevant A: technological background O: non-written disclosure P: intermediate document T: theory or principle underlying the invention E: conflicting application D: document cited in the application L: citation for other reasons
X	The present search report has been drawn up for all claims		&: member of the same patent family, corresponding document
Place of search The Hague		Date of completion of the search 20-12-1978	Examiner GORUN

